

**EFFECTS OF DIFFERENT DRYING METHODS ON THE
NUTRITIONAL, BIOACTIVE, AND SENSORY QUALITIES OF
CORIANDER LEAVES**

A THESIS

BY

MST. MUKTA BANU RINA

Student ID: 1707015

Session: 2023-2024

Semester: January-June, 2024

**MASTER OF SCIENCE (MS)
IN
FOOD PROCESSING AND PRESERVATION**



**DEPARTMENT OF FOOD PROCESSING AND PRESERVATION
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY,
DINAJPUR-5200
JUNE, 2024**

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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

Coriander leaves, valued in culinary, medicinal, and cosmetic fields, degrade quickly post-harvest senescence resulting in large losses. So, this study examined sun drying (SD), cabinet drying (CD), microwave drying (MD), and freeze drying (FD) to determine their impact on the physicochemical and bioactive properties of coriander leaves and their use in vegetable soup. According to the results, FD had the highest lightness (L^* value) at 34.92, while MD had the lowest (16.17). Except for MD, every method successfully kept the green color with negative a^* values. CD had a high chroma (20.17) and a low total color change (2.32), whereas MD showed the opposite. MD lost the most weight (88.27%) while having the quickest drying time (1.28 hours). The results indicate that the SD samples had the highest total phenolic content (TPC) of 120.26 $\mu\text{g GAE/g DM}$, total flavonoid content (TFC) of 64.33 $\mu\text{QE/g DM}$, and antioxidant activity (2.30 $\mu\text{M TE/g DM}$), with CD, MD, and FD following closely after. The CD had the strongest anti-diabetic effects. The levels of chlorophyll retention were lowest in MD and highest in CD in the aspect of chlorophyll b (22.15 $\mu\text{g/ml}$) and total chlorophyll (34.68 $\mu\text{g/ml}$). The CD is the best method for drying coriander leaves, preserving bioactive ingredients, physicochemical characteristics, and sensory appeal. CD samples outperformed others in taste, aroma, and overall quality, especially in vegetable soups, making the CD a cost-effective, efficient, and high-quality drying method compared to SD, MD, and FD.

Keywords: Coriander leaves, drying method, bioactive compound, vegetable soup

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CHAPTER I

INTRODUCTION

1.1 Introduction

Coriander leaves (*Coriandrum sativum* L.) are widely utilized for both culinary and medicinal purposes, widely cultivated worldwide, especially in Asia (Turkey, Iran, Pakistan, India, and Bangladesh) (Jayasuriya *et al.*, 2023; Łyczko *et al.*, 2021). They are quite nutrient-dense, providing a variety of vital elements and vitamins, such as calcium, phosphorus, iron, carotene, thiamine, riboflavin, sodium, potassium, and oxalic acid, along with protein, fat, minerals, fiber, carbohydrates, and water. Additionally, this herb is esteemed for its health benefits, such as strengthening the stomach, aiding digestion, promoting urine secretion and discharge, and reducing fever (Sarimeseli, 2011). Because of its flavor and strong commercial appeal, the plant is widely used in food preparation, fragrances, and cosmetics (Jayasuriya *et al.*, 2023).

The production of coriander leaves in fiscal year 2022-2023 was 8712.26 metric tons in Bangladesh (BBS, 2023) which was abundant for native consumption. Nevertheless, post-harvest senescence's quick drop in coriander leaves quality results in large losses for the sector. Coriander leaves have an extremely short shelf life, even in the refrigerator. However, this has led to a noticeable price increase and a decrease in product supply in the off-season. The post-harvest storage of coriander leaves is impacted by leaves yellowing, shriveling, and chilling harm (Shoko *et al.*, 2022). Coriander leaves must therefore undergo post-harvest treatment, such as drying, to maintain their nutritional value all year round. Undoubtedly, fresh, raw material is the most valuable source of the fragrant and bioactive chemicals present in coriander leaves (Łyczko *et al.*, 2021). However, dried leaves are generally claimed to have three to four times higher active nutrient levels than fresh leaves because they normally lose up to 85% of their weight throughout the drying process (Babu *et al.*, 2018).

Drying is considered one of the ancient and most conventional strategies for preserving biological materials found in diverse leaves. It influences physical, biological, and chemical qualities such as enzymatic activity, microbial spoilage, hardness, fragrance, flavor, color, and odor in addition to lowering the water content (Sarimeseli, 2011). The most common drying methods are natural (in the shade and the sun), hot air, hoover, freeze drying, microwave, and hybrid microwave methods (microwave-hot air, microwave-freeze, microwave-vacuum, etc.). These methods have gained a lot of traction recently. They appear to be very promising

because they provide materials' inner surfaces with uniform energy and high thermal conductivity, save energy, and prevent thermal degradation, which results in high-quality finished products (Hihat *et al.*, 2017; Nurhaslina *et al.*, 2022; Sarimeseli, 2011; Shafi *et al.*, 2020). However, there has been a lack of studies assessing the effects of drying procedures on the nutritional, bioactive, and sensory properties of coriander leaves, despite an abundance of studies on the experimental and modeling elements of leaf drying features. The objective of this research was to determine an economical drying technique that optimized the preservation of nutrients and bioactive components in coriander leaves.

Objectives of this study were to

- ✓ Identify the best drying technique among the sun, cabinet, microwave, and freeze-drying for coriander leaves.
- ✓ Determine the nutritional, bioactive, and sensory qualities of dried coriander leaves.
- ✓ Evaluate the sensory score of vegetable soup prepared with dried coriander leaves

CHAPTER II

REVIEW OF LITERATURE

2.1 Introduction

Coriander (*Coriandrum sativum* L.), a popular culinary herb, is extensively used for its distinctive aroma and health benefits. The preservation of its nutritional and bioactive compounds during processing, particularly drying, is crucial, especially for applications in vegetable soups where both flavor and nutritional content are valued. This review explores the effects of various drying methods on the nutritional, bioactive, and sensory qualities of coriander leaves.

Origins: Coriander leaves, also known as cilantro, trace their origins to regions spanning Southern Europe, North Africa, and Southwestern Asia. Coriander is one of the oldest herbs known to humanity, with evidence of its cultivation dating back at least 7,000 years. Ancient Egyptians used coriander in both culinary and medicinal practices, and coriander seeds were even found in Egyptian tombs, suggesting they were valued in rituals.

The herb was also widely used in ancient Greece and Rome. It spread across Europe and into Asia via trade routes, eventually becoming a staple in various cuisines around the world, particularly in Indian, Middle Eastern, Mediterranean, and Latin American dishes. Its widespread use across different continents illustrates how ancient civilizations valued coriander both for flavor and potential health benefits.

2.1.1 Nutritional quality

The nutritional value of coriander leaves, including vitamins, minerals, and other phytochemicals, can be significantly influenced by the drying method employed. Drying at high temperatures tends to degrade thermolabile nutrients such as vitamin C and carotenoids. For instance, a study by Niamnuy *et al.* (2012) demonstrated that air-drying at temperatures above 50°C led to a substantial reduction in the vitamin C content of coriander leaves. In contrast, freeze-drying, which involves sublimation under low temperatures, better preserves the nutritional content, as noted by Hossain *et al.* (2010).

2.1.2 Bioactive compounds

Coriander leaves are rich in bioactive compounds like polyphenols, flavonoids, and essential oils, which have been linked to various health benefits, including antioxidant, anti-inflammatory, and antimicrobial properties. The drying method impacts the retention of these compounds. According to Toontom *et al.* (2012), freeze-drying was found to retain a higher content of polyphenols and flavonoids compared to hot air drying. Similarly, Cheng *et al.* (2014) reported that microwave drying, although faster, can lead to the degradation of essential oils, which are crucial for the herb's bioactive efficacy.

2.1.3 Sensory qualities

The sensory attributes of coriander, such as color, flavor, and texture, are critical for its acceptance in culinary applications like vegetable soups. Drying methods that involve high temperatures or prolonged exposure can cause discoloration and flavor loss. In a study by Shahin *et al.* (2018), air-dried coriander leaves showed significant color loss and a decrease in volatile compounds responsible for the herb's characteristic aroma. Freeze-drying, on the other hand, was noted to better preserve the sensory qualities, as it minimizes oxidation and thermal degradation.

2.2 Drying

Drying is a crucial step in the processing of coriander leaves to extend their shelf life and facilitate their use in various applications. The most commonly used drying methods include air drying, freeze-drying, microwave drying, solar drying, and vacuum drying. Each of these methods has its advantages and disadvantages, and their effects on the nutritional, bioactive, and sensory qualities of coriander leaves vary.

Air drying: Air drying is one of the oldest and most widely used drying methods due to its simplicity and low cost. However, it is often associated with significant losses in heat-sensitive nutrients and bioactive compounds. Research by Niamnuy *et al.* (2012) highlighted that air drying at temperatures above 50°C led to substantial reductions in the vitamin C content of coriander leaves.

Freeze-drying: Freeze-drying is a method that involves the sublimation of ice under low pressure and temperature. It is highly effective in preserving the nutritional and bioactive components of coriander leaves, as demonstrated by Hossain *et al.* (2010). However, it is more expensive and time-consuming compared to other drying methods.

Microwave drying: Microwave drying offers a faster drying process and is effective in preserving certain bioactive compounds. However, studies such as that by Bhat *et al.* (2018) have shown that it can lead to the degradation of essential oils and other volatile compounds, resulting in a loss of flavor and aroma.

Solar drying: Solar drying is an eco-friendly and cost-effective method, especially in regions with abundant sunlight. However, it is highly dependent on environmental conditions and may result in uneven drying and significant losses in quality. As noted by Kadam *et al.* (2011), solar drying can lead to substantial reductions in the nutrient content of coriander leaves.

Vacuum drying: Vacuum drying involves drying under reduced pressure, which allows for lower drying temperatures and better retention of heat-sensitive nutrients and bioactive compounds. A study by Krokida *et al.* (2001) found that vacuum drying resulted in better preservation of the nutritional and sensory qualities of coriander leaves compared to conventional air drying.

2.2.1 Freeze drying

Freeze drying, also known as lyophilization, is a sophisticated dehydration technique that has gained significant traction across various industries, particularly in the preservation of food, pharmaceuticals, and biological materials. The process is characterized by its ability to remove moisture from materials while preserving their structural integrity, bioactivity, and sensory properties. This unique capability makes freeze drying a critical process in contexts where the preservation of quality is paramount.

2.2.2 Principles of Freeze Drying

Freeze drying operates on the principle of sublimation, where water transitions directly from a solid (ice) to a gaseous state without passing through the liquid phase. The process generally involves three main stages: freezing, primary drying (sublimation), and secondary drying (desorption).

Freezing: In the first stage, the material is rapidly frozen, usually at temperatures ranging from -50°C to -80°C. The goal is to solidify all the water content in the product, minimizing the risk of any liquid phase that could lead to the degradation of sensitive compounds (Tang & Pikal, 2004). The freezing step is crucial as it determines the size of the ice crystals, which subsequently affects the efficiency of the drying process.

Primary Drying (Sublimation): After freezing, the pressure is significantly reduced, usually in a vacuum chamber, and heat is carefully applied to initiate sublimation. During this phase, the frozen water sublimates, leaving behind a porous structure that retains the original shape and volume of the material (Rey, 2010). The primary drying phase is the most critical and time-consuming part of the process, accounting for the majority of the moisture removal.

Secondary Drying (Desorption): In the final stage, the remaining unfrozen water, often bound to the material's matrix, is removed by further lowering the pressure and slightly increasing the temperature. The goal of secondary drying is to reduce the moisture content to levels below 1%, which is necessary to ensure the long-term stability of the product (Liapis & Bruttini, 2006). Applications of Freeze Drying.

2.2.3 Applications of freeze drying

The versatility of freeze drying makes it an essential process in several industries:

Food Industry: Freeze drying is widely used for preserving high-value food products, such as coffee, fruits, and vegetables. The process is particularly beneficial for preserving the nutritional content, flavor, and texture of food, making it a preferred method for producing high-quality, long-lasting products. For example, freeze-dried fruits are often used in cereals and snacks, where the retention of color and flavor is essential (Rey, 2010).

Pharmaceuticals: In the pharmaceutical industry, freeze drying is indispensable for the stabilization of thermolabile substances, such as vaccines, proteins, and antibiotics. Lyophilization helps in maintaining the biological activity and efficacy of these products over extended periods. Moreover, the process allows for the creation of dry powder formulations that are more stable and easier to handle compared to liquid forms (Patapoff & Overcashier, 2002).

Biotechnology: Freeze drying plays a vital role in the preservation of biological materials, including enzymes, bacteria, and cell cultures. The process ensures that these materials retain their viability and activity after rehydration, which is critical for research and industrial applications (Tang & Pikal, 2004).

2.2.4 Advantages of Freeze Drying

The advantages of freeze drying are numerous, particularly in the context of quality preservation:

Nutrient Retention: Unlike other drying methods, freeze drying effectively preserves the nutritional and bioactive compounds within a product. This is because the low temperatures and vacuum conditions minimize chemical reactions that could degrade sensitive nutrients (Rey, 2010).

Extended Shelf Life: Freeze drying significantly reduces the moisture content in products, thereby inhibiting microbial growth and enzymatic activities that could lead to spoilage. This results in products with exceptionally long shelf lives, often spanning several years (Liapis & Bruttini, 2006).

Preservation of Structure and Appearance: The gentle nature of freeze drying allows for the preservation of the physical structure and appearance of the material. This is particularly important for delicate products, such as biological samples and certain food items, where the aesthetic and structural integrity are critical (Patapoff & Overcashier, 2002).

2.2.5 Challenges and Limitations

Despite its numerous advantages, freeze drying is not without its challenges:

High Cost: The equipment and energy requirements for freeze drying are substantial, making it a costly process compared to other dehydration methods. This limits its use to high-value products where the benefits outweigh the costs (Liapis & Bruttini, 2006).

Time-Intensive Process: Freeze drying is inherently slow, often requiring several hours to days to complete, depending on the material and the desired end-product specifications. This extended processing time can be a significant bottleneck in production environments (Tang & Pikal, 2004).

Complexity and Expertise: The successful execution of freeze drying requires specialized equipment and expertise, particularly in controlling the delicate balance of temperature, pressure, and time. This complexity can be a barrier for smaller operations or those new to the technology (Patapoff & Overcashier, 2002).

2.2.6 Cabinet drying

Cabinet drying is a widely used dehydration method, particularly in the food processing and agricultural sectors. This technique involves placing materials inside a controlled environment where heated air is circulated to remove moisture. Cabinet dryers are versatile, offering a practical solution for small- to medium-scale drying operations. They are especially valued for their simplicity, efficiency, and the quality of the dried product.

2.2.7 Principles of Cabinet Drying

Cabinet drying operates on the principle of convective heat transfer, where hot air is passed over the surface of the material, causing moisture to evaporate. The key components of a cabinet dryer include a chamber (or cabinet) where the material is placed on trays or shelves, a heat source, and a fan or blower that circulates the hot air. The air temperature, humidity, and flow rate are carefully controlled to optimize drying efficiency and product quality.

Loading the Material: The material to be dried is uniformly spread on trays or shelves within the cabinet. The thickness and distribution of the material are critical factors that influence the drying rate and uniformity (Kudra & Mujumdar, 2009).

Heating and Air Circulation: Heated air is circulated within the cabinet, typically at temperatures ranging from 40°C to 90°C, depending on the sensitivity of the material. The air flows over and through the material, picking up moisture and carrying it away. The design of the air circulation system is crucial for ensuring even drying across all trays (Perry & Green, 2008).

Moisture Removal: As the hot air passes over the material, moisture is drawn out and expelled from the cabinet through exhaust vents. The moisture content of the material gradually decreases until it reaches the desired level. The drying time can vary from a few hours to several days, depending on the material and the drying conditions (Mujumdar, 2014).

2.2.8 Applications of Cabinet Drying

Cabinet drying is used across a variety of industries due to its versatility and effectiveness:

Food Industry: In the food industry, cabinet drying is commonly used for drying fruits, vegetables, herbs, spices, and meat products. The controlled environment allows for the preservation of flavor, color, and nutritional value, making it ideal for producing high-quality dried foods. For instance, cabinet drying is often employed in the production of dried apples, apricots, and tomatoes, where retention of sensory qualities is critical (Ahmed, 2017).

Agriculture: Farmers use cabinet dryers to preserve surplus crops, particularly in regions where other preservation methods are less feasible. Drying extends the shelf life of produce and reduces post-harvest losses. Cabinet dryers are especially beneficial for drying grains, seeds, and nuts, where maintaining a low moisture content is essential for preventing spoilage and aflatoxin contamination (Hii *et al.*, 2012).

Pharmaceuticals and Chemicals: In the pharmaceutical and chemical industries, cabinet drying is used for drying raw materials, intermediates, and finished products. The process ensures that moisture-sensitive compounds are thoroughly dried without exposure to high temperatures that could degrade their potency or stability. This is particularly important for drying herbal extracts, powders, and granules (Mujumdar, 2014).

2.2.9 Advantages of Cabinet Drying

Cabinet drying offers several advantages, particularly in terms of cost-effectiveness, ease of use, and product quality:

Cost-Effective: Cabinet dryers are relatively inexpensive to purchase and operate, making them accessible for small- to medium-scale operations. Their simplicity reduces maintenance costs and the need for specialized training (Perry & Green, 2008).

Controlled Drying Conditions: The ability to precisely control temperature, humidity, and airflow within the cabinet ensures consistent and high-quality drying. This is particularly important for sensitive materials that require specific drying conditions to maintain their quality (Kudra & Mujumdar, 2009).

Versatility: Cabinet dryers can be used for a wide range of materials, from food products to pharmaceuticals. Their adaptability makes them a popular choice across various industries (Mujumdar, 2014).

2.2.10 Challenges and Limitations

While cabinet drying is effective for many applications, it does come with certain limitations:

Non-Uniform Drying: One of the main challenges with cabinet drying is achieving uniform drying across all trays. Variations in airflow and temperature within the cabinet can lead to uneven drying, which can affect product quality and shelf life (Ahmed, 2017).

Longer Drying Times: Compared to more advanced drying technologies, cabinet drying can be relatively slow, particularly for high-moisture materials or when large volumes are being processed. This can limit throughput in high-demand operations (Hii *et al.*, 2012) or those new to the technology (Patapoff & Overcashier, 2002).

2.2.11 Recent Advances in Cabinet Drying

Advancements in cabinet drying technology are focused on improving efficiency, reducing energy consumption, and enhancing product quality. Innovations include the development of

hybrid systems that combine cabinet drying with other drying methods, such as microwave or infrared drying, to reduce drying times and energy use (Mujumdar, 2014). Additionally, improvements in airflow design and temperature control have led to more uniform drying and better preservation of product quality.

2.2.12 Sun drying

Sun drying is one of the oldest and most traditional methods of food preservation, relying on the natural heat of the sun and air circulation to remove moisture from products. This technique has been used for centuries to preserve fruits, vegetables, grains, and other agricultural products. Despite the advent of more advanced drying technologies, sun drying remains a widely used method, particularly in developing regions where access to energy and technology is limited.

2.2.13 Principles of Sun Drying

Sun drying is a relatively simple process that leverages the sun's radiant energy to evaporate moisture from food. The process typically involves spreading the food items in thin layers on the ground, on drying racks, or on trays, allowing them to be exposed to direct sunlight. Air circulation plays a critical role in removing the moisture-laden air from the drying surface, thereby facilitating the drying process.

Preparation of the Material: Before sun drying, the food items are usually washed, peeled, and cut into uniform pieces to ensure even drying. Fruits like grapes (for raisins), apricots, and figs are often pre-treated with sulfur dioxide or other preservatives to prevent spoilage and discoloration during the drying process (Abano & Sam-Amoah, 2011).

Exposure to Sunlight: The prepared food is spread out in a single layer on a drying surface, such as a mat, tray, or rack, which is placed in a location with ample sunlight and good air circulation. The duration of sun drying varies depending on the type of food, the intensity of sunlight, and the ambient temperature and humidity. For example, fruits may take several days to weeks to dry fully, while grains may dry in a shorter period (Afolabi, 2014).

Moisture Evaporation: As the food is exposed to the sun, the heat causes the moisture within the food to evaporate. The moisture then dissipates into the surrounding air. Regular turning or stirring of the food is often necessary to ensure even drying and to prevent spoilage due to uneven moisture distribution (Ekechukwu & Norton, 1999).

2.2.14 Applications of Sun Drying

Sun drying is predominantly used in the agricultural sector for preserving crops during harvest seasons when there is a surplus:

Fruits and Vegetables: Sun drying is commonly used for drying fruits such as grapes (to make raisins), apricots, figs, and tomatoes. The method is favored in regions with hot, dry climates, where the intense sunlight and low humidity provide ideal conditions for drying. In addition to fruits, sun drying is also used for drying vegetables like peppers, okra, and onions, which can be stored for long periods without refrigeration (Abano & Sam-Amoah, 2011).

Grains and Legumes: In many developing countries, sun drying is the primary method used for drying grains such as rice, maize, wheat, and millet, as well as legumes like beans and lentils. After harvest, these crops are spread out in large open spaces to dry before storage. This process helps to reduce the moisture content to levels that inhibit microbial growth and prevent spoilage during storage (Afolabi, 2014).

Spices and Herbs: Sun drying is also used for preserving herbs and spices, such as chilies, coriander, and basil. The method helps to retain the essential oils and flavors of these products, making them suitable for long-term storage and use in cooking and medicine (Ekechukwu & Norton, 1999).

2.2.15 Advantages of Sun Drying

Sun drying offers several advantages, especially in resource-limited settings:

Low Cost: One of the most significant advantages of sun drying is its low cost. The method requires minimal investment in equipment, as it primarily relies on natural sunlight and air circulation. This makes it an accessible and affordable preservation method, especially for small-scale farmers and communities in developing regions (Ekechukwu & Norton, 1999).

Simplicity and Accessibility: The simplicity of sun drying makes it easy to implement with minimal training or technical knowledge. It does not require complex machinery or energy inputs, making it a practical option for rural and remote areas (Abano & Sam-Amoah, 2011).

Eco-Friendly: Sun drying is an environmentally friendly process that uses renewable solar energy, producing no greenhouse gas emissions or waste products. This makes it a sustainable method of food preservation (Afolabi, 2014).

2.2.16 Challenges and Limitations

Despite its advantages, sun drying also presents several challenges and limitations:

Dependence on Weather Conditions: Sun drying is highly dependent on favorable weather conditions, such as consistent sunlight and low humidity. In regions with unpredictable weather or during the rainy season, the effectiveness of sun drying can be compromised, leading to prolonged drying times or incomplete drying, which increases the risk of spoilage (Ekechukwu & Norton, 1999).

Risk of Contamination: Open-air sun drying exposes food to dust, insects, and other contaminants, which can compromise the safety and quality of the dried products. In some cases, pests such as birds and rodents may also damage the food during drying (Afolabi, 2014).

Quality Control Issues: Achieving uniform drying can be challenging in sun drying, leading to variations in moisture content within the same batch of food. This can result in uneven quality, with some portions being over-dried (leading to loss of texture and flavor) and others under-dried (increasing the risk of microbial growth and spoilage) (Abano & Sam-Amoah, 2011).

2.2.17 Improving Sun Drying Efficiency

Recent efforts to improve the efficiency and safety of sun drying have focused on developing low-cost, small-scale solar dryers. These dryers use transparent covers and enhanced air circulation systems to protect the food from contaminants and pests while speeding up the drying process by trapping heat and reducing drying times. Such innovations help to mitigate some of the challenges associated with traditional sun drying, offering a more controlled environment while still relying on renewable solar energy (Ekechukwu & Norton, 1999).

2.2.18 Microwave drying

Microwave drying is an advanced drying technology that utilizes microwave energy to remove moisture from various materials, including food products, pharmaceuticals, and industrial materials. This method has gained popularity due to its ability to significantly reduce drying time, enhance product quality, and offer energy efficiency compared to conventional drying methods. The rapid and volumetric heating provided by microwaves makes this technique particularly advantageous for moisture removal in heat-sensitive materials.

2.2.19 Principles of Microwave Drying

Microwave drying is based on the interaction of microwave radiation with the water molecules within a material. Microwaves are a form of electromagnetic radiation with frequencies typically ranging from 300 MHz to 300 GHz. In microwave drying, the most common frequency used is 2.45 GHz. This frequency is highly effective at causing polar water molecules to oscillate, generating heat through molecular friction, which leads to the evaporation of moisture from the material (Tang, 2005).

Microwave Absorption and Heating: The microwave energy penetrates the material and is absorbed by the water molecules, causing them to heat up. This heating occurs throughout the entire volume of the material, unlike conventional drying methods that rely on surface heat transfer. This results in a more uniform drying process and reduces the likelihood of overheating the material's surface while leaving the interior moist (Mujumdar, 2014).

Moisture Migration and Evaporation: As the water molecules within the material are heated, the vapor pressure inside the material increases, driving moisture toward the surface, where it evaporates. The rapid heating and moisture migration characteristic of microwave drying help to minimize the drying time, making it a highly efficient process (Maskan, 2001).

Continuous and Batch Processes: Microwave drying can be implemented in both continuous and batch processes. In a continuous process, the material moves through a microwave field on a conveyor belt, while in a batch process, the material remains stationary within the microwave chamber. Both methods offer flexibility in drying different types and volumes of materials (Feng, 2013).

2.2.20 Applications of Microwave Drying

Microwave drying has a broad range of applications across various industries:

Food Industry: Microwave drying is widely used in the food industry for drying fruits, vegetables, herbs, spices, and other food products. The ability to quickly remove moisture while preserving nutritional content, flavor, and color makes microwave drying ideal for high-quality food processing. For instance, microwave-dried fruits and vegetables retain better texture and taste compared to those dried using conventional methods (Duan *et al.*, 2011).

Pharmaceuticals: In the pharmaceutical industry, microwave drying is used to dry heat-sensitive materials such as powders, granules, and herbal extracts. The gentle heating

provided by microwaves helps to preserve the bioactivity and potency of these products. Additionally, microwave drying is employed in the production of tablets, where uniform drying is crucial for product consistency (Mujumdar, 2014).

Ceramics and Polymers: Microwave drying is also used in the processing of ceramics and polymers. In ceramics, microwave drying helps to reduce the time required to dry green bodies before firing, resulting in energy savings and improved product quality. In polymer processing, microwave drying is used to remove residual solvents and moisture from polymeric materials, enhancing their mechanical properties (Vollmer, 2004).

2.2.21 Advantages of Microwave Drying

Microwave drying offers several significant advantages over conventional drying methods:

Reduced Drying Time: One of the primary advantages of microwave drying is the substantial reduction in drying time. Because microwaves heat the material volumetrically, moisture is removed more quickly and uniformly, often reducing drying times by up to 90% compared to traditional methods (Maskan, 2001).

Energy Efficiency: Microwave drying is generally more energy-efficient than conventional drying methods, as it directly heats the water molecules within the material rather than heating the air or the drying chamber. This direct heating minimizes energy losses and leads to lower overall energy consumption (Tang, 2005).

Enhanced Product Quality: Microwave drying often results in higher quality products, as the rapid drying process helps to preserve the material's color, texture, and nutritional value. For instance, microwave-dried fruits and vegetables tend to retain more of their vitamins and antioxidants compared to those dried using hot air (Duan *et al.*, 2011).

2.2.22 Challenges and Limitations

Despite its advantages, microwave drying also has several challenges and limitations:

Non-Uniform Heating: One of the main challenges with microwave drying is achieving uniform heating throughout the material. Differences in moisture content, density, and geometry can lead to uneven heating, resulting in "hot spots" where the material may become overheated, potentially leading to degradation or charring (Feng, 2013).

Limited Penetration Depth: Microwaves have a limited penetration depth, meaning that the drying process is most effective for thin layers of material. For thicker materials, microwave

drying may need to be combined with other drying methods to achieve uniform moisture removal (Mujumdar, 2014).

High Initial Cost: The initial cost of microwave drying equipment is typically higher than that of conventional dryers. This can be a barrier to adoption, particularly for small-scale operations. However, the long-term energy savings and improved product quality often justify the investment (Maskan, 2001).

2.2.23 Recent Advances in Microwave Drying

Recent advances in microwave drying technology have focused on overcoming its challenges and enhancing its efficiency. For instance, hybrid drying systems that combine microwaves with other drying methods, such as hot air, vacuum, or freeze drying, have been developed to improve drying uniformity and product quality. Additionally, the use of smart sensors and control systems allows for real-time monitoring and adjustment of the drying process, helping to prevent overheating and optimize energy use (Tang, 2005).

2.3 Effects of Drying Methods on Coriander Leaves

2.3.1 Nutritional impact of drying methods

Drying is a widely used method to preserve the nutritional qualities of coriander leaves, but the technique applied can lead to varying levels of nutrient retention. Nutritional components such as vitamins, minerals, and antioxidants are sensitive to heat, light, and oxygen, which can be altered during drying (Abirami *et al.*, 2014). Sun drying, a traditional method, is often criticized for its extended drying time and exposure to light, leading to significant losses in vitamin C and carotenoids (Zhang *et al.*, 2006). In contrast, oven drying at controlled temperatures has been found to better preserve these nutrients due to reduced exposure to light and oxygen (Kou *et al.*, 2013).

Freeze-drying, known for its ability to maintain the structural integrity and nutrient content of fresh herbs, is highly effective in preserving vitamin C and other heat-sensitive compounds (Ratti, 2001). Research by Kandoliya *et al.* (2015) demonstrated that freeze-dried coriander leaves retained higher levels of essential nutrients compared to those dried using air or sun drying methods. Similarly, microwave drying has shown promising results in retaining nutrients while reducing drying time, which minimizes nutrient degradation (Sharma & Prasad, 2006).

2.3.2 Sensory quality changes

The sensory qualities of coriander leaves, including color, aroma, and flavor, are critical for their acceptance in vegetable soups. Drying methods can significantly alter these sensory attributes, affecting the overall quality of the final product. Color retention is particularly important, as it is often associated with freshness and nutritional quality. Studies have shown that sun drying leads to considerable color loss due to pigment degradation (Hernández *et al.*, 2010). Oven drying at high temperatures can also cause browning, which negatively impacts the visual appeal (Di Cesare *et al.*, 2012).

In terms of aroma and flavor, the essential oils in coriander leaves are responsible for their characteristic sensory properties. These oils are volatile and can be lost during drying, particularly at higher temperatures. Freeze-drying has been reported to preserve the aroma and flavor of coriander leaves better than other drying methods, as it reduces the loss of volatile compounds (Reis *et al.*, 2013). Microwave drying, while faster, can cause uneven heating, potentially leading to "hot spots" that degrade essential oils and alter flavor (Drouzas *et al.*, 1999).

2.4 Application of coriander leaves in vegetable soups

Coriander leaves are commonly used in vegetable soups to enhance flavor and add nutritional value. The choice of drying method can significantly affect the quality of the final soup product. For instance, freeze-dried coriander leaves are often preferred in high-quality soup formulations due to their superior retention of nutrients and flavor (Sharma & Prasad, 2006). However, in commercial soup mixes, where cost is a major consideration, air-dried coriander leaves are more commonly used despite some compromise on sensory qualities (Shahin *et al.*, 2018).

Overall applications of coriander leaves: Coriander leaves (cilantro) are widely used around the world for their unique flavor, aroma, and health benefits. Here's an overview of their applications:

1. Culinary Use: Coriander leaves are popular in global cuisines, adding freshness to dishes. They are used in:

Garnishing: Commonly sprinkled on soups, curries, salads, and stews for a fresh taste.

Sauces & Chutneys: Blended into sauces, like Indian chutneys, Thai sauces, and Mexican salsas.

Seasoning: Combined with other spices in marinades and dressings to flavor meat, fish, or vegetables.

2. Medicinal and Health Benefits: Traditionally used for various health purposes, coriander leaves are thought to have properties that can:

Aid digestion and reduce bloating.

Help manage blood sugar levels.

Provide antioxidant benefits, which support immune health.

3. Cosmetic Use: Coriander leaves are also used in skincare as their extracts are believed to help with skin irritation, detoxification, and complexion improvement.

4. Aromatherapy: Due to their refreshing fragrance, coriander leaves can sometimes be found in essential oil blends for relaxation and stress relief.

5. Environmental & Agricultural Use: Known to attract beneficial insects, coriander is also planted in gardens to support pollination and help with pest control.

2.4.1 Flavor enhancement

Coriander leaves are renowned for their unique aroma and flavor, which can significantly enhance the sensory appeal of vegetable soups. The leaves contain essential oils, including linalool and geraniol, which impart a fresh, citrusy, and slightly peppery taste to dishes (Asgarpanah & Kazemivash, 2012). This flavor profile complements a wide variety of vegetables, making coriander a versatile ingredient in soups. According to Bhattacharjee *et al.* (2014), the addition of fresh coriander leaves at the end of the cooking process helps preserve their volatile compounds, thereby maximizing flavor intensity.

2.4.2 Nutritional contribution

Coriander leaves are a rich source of vitamins (such as vitamin C, vitamin K, and vitamin A), minerals (including potassium, calcium, and magnesium), and dietary fiber (Kandoliya *et al.*, 2015). When added to vegetable soups, coriander enhances the nutritional value of the dish, contributing essential nutrients that support overall health. A study by Rahim *et al.* (2014) found that soups fortified with coriander leaves had higher levels of antioxidants and exhibited improved nutritional profiles, particularly in terms of vitamin C and beta-carotene content.

2.4.3 Bioactive and health benefits

Coriander leaves are not only valued for their flavor and nutrition but also for their bioactive compounds, which have been linked to various health benefits. The leaves contain polyphenols, flavonoids, and essential oils with potent antioxidant, anti-inflammatory, and antimicrobial properties (Singh *et al.*, 2012). Incorporating coriander leaves into vegetable soups may confer these health benefits to consumers, particularly in enhancing immune function and reducing inflammation. For example, a study by Al-Juhaimi *et al.* (2014) highlighted that soups containing coriander leaves exhibited higher antioxidant activity, which could help in neutralizing free radicals and preventing oxidative stress-related diseases.

2.4.4 Cultural and culinary uses

In many culinary traditions, coriander leaves are a staple ingredient in soups and broths. In South Asian cuisines, for instance, coriander is often added to lentil-based soups (dals) and vegetable broths for its fresh aroma and flavor. Similarly, in Mexican cuisine, coriander leaves are a key ingredient in soups like "sopa de cilantro," where they provide a refreshing taste that balances the richness of the broth (González-Aguilar *et al.*, 2015). The herb's versatility and wide acceptance across different cultures underscore its importance in vegetable soup preparations.

2.4.5 Preservation and use in soup mixes

Drying is a common method for preserving coriander leaves for later use in soups. Dried coriander retains many of the herb's flavors, although some volatile compounds may be lost during the drying process (Hossain *et al.*, 2010). Freeze-dried coriander leaves, in particular, are popular in commercial soup mixes due to their superior retention of flavor and nutrients. These dried leaves can be easily rehydrated and incorporated into soups, providing a convenient way to enjoy the benefits of coriander year-round (Sharma & Prasad, 2006).

2.5 Importance of vegetable soup

Vegetable soups are an integral part of diets around the world, offering a wide range of health benefits and serving as a versatile culinary option. Their importance extends beyond mere nutrition, encompassing aspects of health promotion, disease prevention, and cultural significance. This section explores the various facets of vegetable soup's importance, supported by scholarly references in APA style.

2.5.1 Dietary benefits

Vegetable soups are nutrient-dense, providing a variety of essential vitamins, minerals, and fiber while being relatively low in calories. They serve as an effective way to increase the intake of vegetables, which are key sources of dietary fiber, antioxidants, and phytonutrients. According to a study by Mozaffarian *et al.* (2011), consuming a diet rich in vegetables, including in soup form, is associated with a lower risk of chronic diseases such as cardiovascular disease, type 2 diabetes, and certain cancers. The high water content in vegetable soups also contributes to hydration and satiety, which can support weight management efforts (Rolls *et al.*, 2004).

2.5.2 Role in disease prevention

The consumption of vegetable soups has been linked to various health benefits, particularly in the prevention and management of chronic diseases. The bioactive compounds found in vegetables, such as flavonoids, carotenoids, and polyphenols, exhibit antioxidant and anti-inflammatory properties, which can reduce oxidative stress and inflammation in the body (Liu, 2013). For instance, a study by Wang *et al.* (2014) found that individuals who regularly consumed vegetable-rich diets, including soups, had a lower incidence of cardiovascular diseases. Additionally, the high fiber content in vegetable soups can help regulate blood sugar levels and improve digestive health, reducing the risk of type 2 diabetes and gastrointestinal disorders (Slavin, 2013).

2.5.3 Convenience and versatility

Vegetable soups are highly versatile and can be adapted to include a wide range of ingredients, making them an ideal choice for diverse dietary needs and preferences. They can be easily modified to suit vegetarian, vegan, gluten-free, or low-sodium diets, ensuring that they can cater to different nutritional requirements (Harnack *et al.*, 2017). Moreover, vegetable soups can be prepared in large quantities and stored for later use, making them a convenient meal option for busy individuals and families. This convenience, combined with their nutritional benefits, makes vegetable soups an important component of a balanced diet.

2.5.4 Civilizing and cooking significance

Vegetable soups hold significant cultural importance in many parts of the world, often being associated with traditional healing practices and comfort food. For example, in many Asian cultures, vegetable soups are consumed as part of a balanced diet to maintain health and well-being, particularly during illness (Sung *et al.*, 2012). In Mediterranean countries, soups made

from vegetables, legumes, and herbs are a staple of the diet and are considered to be part of the reason for the longevity and lower rates of chronic disease observed in these populations (Sofi *et al.*, 2010). The cultural significance of vegetable soups highlights their role not only as a source of nutrition but also as a means of preserving culinary traditions and promoting social cohesion.

2.5.5 Environmental and economic considerations

Vegetable soups are often made from locally sourced, seasonal vegetables, which can help reduce the environmental impact of food production and support sustainable agriculture. By utilizing a variety of vegetables, including those that might otherwise go to waste, vegetable soups contribute to reducing food waste and promoting food security (Gustavsson *et al.*, 2011). Additionally, vegetable soups are generally cost-effective to prepare, making them an accessible and affordable option for people across different socioeconomic backgrounds.

2.6 Coriander vegetable soup in Bangladesh

In Bangladesh, coriander leaves are a staple in many traditional dishes, and their use in soups is widespread. The preparation of coriander vegetable soup typically involves a blend of seasonal vegetables, coriander leaves, and a combination of spices such as cumin, turmeric, and chili powder. The soup often begins with the frying of onions, garlic, and ginger in oil, followed by the addition of chopped vegetables like potatoes, carrots, and tomatoes (Alam *et al.*, 2014). Once the vegetables are partially cooked, water or vegetable broth is added, and the mixture is simmered until the vegetables are tender. Fresh coriander leaves are added towards the end of cooking to retain their flavor and nutritional qualities.

Coriander leaves in Bangladesh are sometimes dried and preserved for off-season use, particularly in rural areas. However, fresh coriander is preferred for its more intense flavor and aroma (Haque *et al.*, 2017). The soup is often garnished with additional fresh coriander leaves and served with rice or flatbreads. The use of coriander in soups is not only for its flavor but also for its digestive benefits, as it is believed to aid in digestion and prevent bloating (Islam & Jalal, 2014).

2.7 Coriander vegetable soup around the world

India: In India, coriander leaves are a crucial ingredient in many vegetarian soups. Coriander-tomato soup is a popular variation where tomatoes are blended with spices and fresh coriander to create a tangy and aromatic soup (Raghavan, 2007). The preparation typically involves sautéing onions, garlic, and ginger, adding chopped tomatoes, and cooking

them down before blending into a smooth consistency. Fresh coriander leaves are then added, along with a dash of lemon juice to enhance the flavor. This soup is often served as a starter or as part of a light meal. Middle East and North Africa: In Middle Eastern and North African cuisine, coriander is frequently used in soups, especially those based on lentils or chickpeas. For example, harira, a traditional Moroccan soup, includes fresh coriander leaves as a key ingredient, along with lentils, chickpeas, tomatoes, and spices such as cumin and cinnamon (Seddik *et al.*, 2013). The preparation involves simmering the ingredients in a rich broth, often with the addition of meat, and garnishing with a generous amount of fresh coriander just before serving. Coriander adds a fresh, herbal note that balances the richness of the soup.

Latin America: In Latin American countries, particularly in Mexico, coriander (known as cilantro) is a staple in many dishes, including soups. Sopa de cilantro is a traditional Mexican soup that highlights the flavor of coriander. The preparation involves blending fresh coriander leaves with onions, garlic, and sometimes green chilies, then cooking the mixture with chicken or vegetable broth (Kennedy, 2003). The soup is often thickened with a starch such as potato or tortilla strips and served with a garnish of fresh coriander and lime.

Southeast Asia: In Southeast Asian countries like Thailand and Vietnam, coriander is used in soups that are light and fragrant. Tom Yum, a famous Thai soup, often includes fresh coriander leaves added at the end of cooking to complement the flavors of lemongrass, lime, and chili (Sompong, 2010). The preparation typically involves boiling a broth with herbs and spices, adding vegetables or seafood, and finishing with fresh coriander for a burst of freshness. Similarly, in Vietnam, coriander is commonly used as a garnish for pho, a noodle soup that is rich in herbs and spices (Nguyen, 2011).

CHAPTER III

MATERIALS AND METHODS

3.1 Collection of samples

Freshly picked coriander leaves from the local market in Basherhat, Dinajpur, Bangladesh, were used for the research. For the investigations, the leaves were cut off from the main stems and roots.

3.2 Different drying processes and conditions of the coriander leaves

Firstly, the coriander leaves were washed thoroughly to remove the soil particles. Then, it was taken in the strainer to rinse the excess washing water. Finally, the samples were ready for drying in different methods. Four different drying techniques were used for the investigations: direct sun, microwave, cabinet, and freeze-drying.

Sun drying method: Coriander leaves were placed in the open sun with a uniform thickness of 0.5 mm. The samples were dried at temperature 32°C-34°C and relative humidity (%RH) 51-60%. It took almost 5 hours to dry the samples at a moisture content of 5-6%.

Microwave drying method: The samples were placed on a glass plate with a uniform bed thickness of 0.5 mm in the microwave (LG, Model No. MC2844EB, Frequency: 2450 MHz). The microwave power was set at 510 W to dry the coriander leaves and it took 1.28 hours to dry the samples.

Cabinet drying method: In the cabinet dryer, the samples were placed uniformly in the dryer tray (0.5mm thickness) and dried at 60°C with 1-2 m/s air velocity. The drying time was almost 3.15 hours to dry the leaves.

Freeze drying method: Coriander leaves were held at -25°C for 12 hours prior to freeze drying. The dryer's vacuum pressure was set to 20 Pa, and the plate temperature was kept at 20°C. The temperature of the condenser was set to -60°C. The drying process was conducted at a temperature of 30°C for 17 hours.

3.3 Physicochemical properties of dried coriander leaves

3.3.1 Moisture content and weight loss

The moisture content of coriander leaves was examined by a digital moisture analyzer (Model: XY-105MW, China). An electronic balance (AS 220.R2, Radwag, Poland) was used to weigh the samples with a precision of 0.001 g. The weight loss (WL) % was computed with the following formula (Sarkar *et al.*, 2024):

$$WL = \frac{W_i - W_f}{W_i} \times 100 \dots \dots \dots (1)$$

Where, WL stands for weight loss (%), W_i for the initial weight (g), and W_f for the end weight (g)

3.3.2 Color measurement

The color measurement was conducted utilizing a high-quality colorimeter (BCM 200, Biobase, China). 'L*', 'a*', and 'b*' were the units used to quantify color-magnitude, with the vertical axis (luminance, L*) representing the brightness or darkness. The chromatic component of the solid was represented by the values a^* (+) for the presence of red, a^* (-) for the presence of green, b^* (+) for the presence of yellow, and b^* (-) for the presence of blue (Krithika & Radhai Sri, 2014).

The following represents the total color differences (ΔE), which indicates the variation in color from fresh and dried leaves of coriander (Equation 2), and the chroma which indicates the intensity of color (Equation 3):

$$\Delta E = \sqrt{\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}} \dots \dots \dots (2)$$

$$Chroma = \sqrt{a^{*2} + b^{*2}} \dots \dots \dots (3)$$

3.4 Solvent Extraction

The samples were extracted with minimal modifications to the methodology outlined by (Islam *et al.*, 2021). A solid-to-liquid ratio of 1:20 (g/ml) was achieved by mixing 50 ml of an 80% methanol solution with 2.5 g of desiccated coriander leaves in a 100 ml glass conical flask. A magnetic agitator was used to extract the mixture at room temperature. It was run for 30 minutes at 50 revolutions per minute (rpm). The samples were subsequently centrifuged (Model MF-300 from Human Lab Instrument Co., Korea) at 4000 rpm for 10 minutes. Before analysis, the supernatant was filtered using Whatman no. 1 filter paper and moved with a 10 ml plastic syringe.

3.5 Determination of total phenolic content

With a few minor modifications, the Folin-Ciocalteu test was used to quantify the total phenolic content (TPC), following the approach described by Rahman *et al.* (2024). 500 μ l of the Folin–Ciocalteu solution was mixed with 500 μ l of the sample extract. Subsequently, the mixture was mixed with 1 ml of a 7.5% sodium bicarbonate solution. Then distilled water

was used to increase the capacity to 10 ml. The mixture was stirred with a vortex mixer for a brief duration and then allowed to settle at room temperature in a light-free environment for thirty-five minutes. Following that, the mixture was centrifuged for 10 minutes at 4000 revolutions per minute. Utilizing a UV-Vis spectrophotometer (UV-1800, Shimadzu Scientific Instruments Inc., USA), the absorbance was measured at 750 nm. Gallic acid was used to create a calibration standard curve, with values ranging from 0 to 200 μM . The calibration curve showed a 0.9976 r^2 coefficient of determination, indicating a good linear relationship. Micrograms of gallic acid equivalent per gram of dry sample ($\mu\text{g GAE/g DM}$) were the unit of measurement used to express the results.

3.6 Determination of total flavonoid content

The colorimetric technique outlined by Rahman *et al.* (2024) was utilized to determine the total flavonoid content (TFC). The range of 0 to 300 μM was utilized in a standard calibration curve for quercetin. The quercetin equivalents in microgram per gram ($\mu\text{g QE/g DM}$) of the sample were used to represent the TFC values. In a centrifuge tube, 1 ml of extract, 0.3 ml of 5% NaNO_3 , and 4 ml of distilled water were mixed. After adding 0.3 ml of 10% AlCl_3 to the containers and letting them stand for 5 minutes, the reaction mixture was allowed to stand for 1 minute. After that, the liquid was quickly vortexed with the addition of 2.4 ml of distilled water and 2 ml of 1 M NaOH . After centrifuging the containers for 5 minutes at 4000 $\times g$, they were left at room temperature in the dark for 15 minutes. By replacing the extract with methanol, a baseline was created, and this was used to measure the absorbance at 510 nm.

3.7 Determination of DPPH free radical scavenging activity

The DPPH test was used to measure the coriander leaves' antioxidant capacity. This procedure was followed in accordance with the guidelines provided by Hasan *et al.*, (2022). In particular, 100 ml of 80% methanol was used to dissolve 5.126 mg of DPPH, and the mixture was then ultrasonically agitated for five minutes. After 30 minutes of incubation, the absorbance of a combination made up of 50 μl of the extracted sample and 1.950 ml of the DPPH mixture was assessed at 515 nm through the spectrophotometer (UV 1900i, Shimadzu, Japan). The findings were presented as $\mu\text{M Trolox/g DM}$ or micromoles of Trolox per gram of dried leaves.

3.8 Determination of chlorophyll content

With minimal modifications, the chlorophyll levels were determined using the methodology outlined by Kumar *et al.*, (2015). An acetone-hexane (4:6) mixture was employed to extract

the pigments in the sample in a simultaneous manner. The optical density of each supernatant was determined at wavelengths 663 and 645 nm using a UV/VIS spectrometer (UV 1900i, Shimadzu, Japan). To calculate the amount of chlorophyll a, chlorophyll b, and total chlorophyll in µg/ml, the following formulas were used.

$$\text{Chlorophyll } a \left(\frac{\mu\text{g}}{\text{ml}} \right) = 12.72A_{663} - 2.59A_{645} \dots \dots \dots (4)$$

$$\text{Cholorophyll } b \left(\frac{\mu\text{g}}{\text{ml}} \right) = 22.9A_{645} - 4.67A_{663} \dots \dots \dots (5)$$

$$\text{Total Chlorophyll} = 20.31A_{645} + 8.05A_{663} \dots \dots \dots (6)$$

Where, A_{663} and A_{645} , are the absorbance at 663 and 645, respectively.

3.9 Determination of antidiabetic activity

The dried coriander leaves were examined for their antidiabetic action, specifically their ability to block α -glucosidase, using the modified approach of Rahman *et al.*, (2024). To be exact, 1800 µl of a 0.1 M phosphate buffer (pH 6.9) containing a 0.1 U/ml α -glucosidase solution was combined with 50 µl of the extracted material. After a process lasting 10 minutes at 25°C, a mixture having a 0.1 M concentration of phosphate buffer and a pH of 6.9 was mixed with 50 µl of p-Nitrophenyl- α -D-glucopyranoside at a concentration of 5 mM. After that, the combined mixture was incubated at 25°C for an extra five minutes. The absorbance at a wavelength of 405 nm was measured with a spectrophotometer. Using acarbose as the reference standard, the result was expressed as µM acarbose equivalents per gram of dried material (µM acarbose/g DM).

3.10 Sensory score of dried coriander leaves

The dehydrated coriander powder was subjected to sensory evaluation at Hajee Mohammad Danesh Science and Technology University in Dinajpur. The panel of 25 judges, consisting of ten females, ten males, and five local market merchants from Dinajpur, spanning an age range of 20 to 55 years. All individuals, both female and male, possessed advanced degrees and worked as graduate students and teachers specializing in the field of food technology. The panelists were directed to assess and allocate scores based on a range of qualities, including visual inspection, aroma, texture and touch, taste, and overall acceptability.

A hedonic rating scale ranging from 1 to 9 was used, where 1 represented extreme dislike, 2 strong dislikes, 3 moderate dislikes, 4 mild dislikes, 5 neutral, 6 slight likings, 7 moderate likings, 8 strong likings, and 9 extreme likings.

3.11 Implementation of the dried coriander leaves in vegetable soup

The preparation of vegetable soup was conducted by following the Bukya *et al.* (2018) method with slight modification. First, 2 tablespoons of corn flour were dissolved in 1/2 cup of water in a small bowl. Then, 2 tablespoons of oil were heated in an infrared oven set to 1000W. Chopped garlic 2 cloves was added and sautéed for 20-30 seconds. Next, 1/4 cup of grated carrot, 1 chopped green chili, and 1/4 cup of grated cabbage were added and sautéed for 1-2 minutes. The dissolved corn flour was then added and mixed well. An egg was added directly to the soup with continuous stirring. Two cups of milk were added, and lumps were prevented by constantly stirring. The mixture was cooked for 4-5 minutes. After that, three and a half cups of water and salt were added, and the soup was cooked until it started to boil. Then, different formulations added 100 g of coriander leaves (Dried or fresh) to the soup. Finally, the oven was turned off. The total cooking time was 25 minutes. The formulation of the soup was:

S₁= Soup with sun-dried coriander leaves

S₂= Soup with cabinet-dried coriander leaves

S₃= Soup with microwave-dried coriander leaves

S₄= Soup with freeze-dried coriander leaves

Control = Soup with fresh coriander leaves

3.12 Sensory evaluation of vegetable soup using dried coriander leaves

To evaluate the sensory qualities of dried coriander leaves vegetable soup, including color, flavor, texture, taste, and overall quality, (Rahman *et al.*, 2024) author's methodology was implemented. At Hajee Mohammad Danesh Science and Technology University, 25 evaluators, including graduate students and food technology experts, participated in the evaluation. Testing was conducted in an environment that was both spotless and odor-free, and filtered water was provided to cleanse the palate between samples. A hedonic rating scale ranging from 1 to 9 was used, where 1 represented extreme dislike, 2 strong dislikes, 3 moderate dislikes, 4 mild dislikes, 5 neutral, 6 slight likings, 7 moderate likings, 8 strong likings, and 9 extreme likings.

3.13 Statistical analysis

The experimental data were analyzed using SPSS (IBM version 27). Components associated with dried coriander leaves and dried coriander leaves incorporated into vegetable soup were examined in the investigation. One-way ANOVA was employed to evaluate the mean responses across interventions and storage conditions if significant differences in means were identified through analysis of variance (ANOVA). Subsequent post-hoc comparisons were conducted.

CHAPTER IV

RESULT AND DISCUSSION

4.1 The physicochemical characteristics of coriander leaves

Table 4.1 shows the different drying processes that were applied to dried coriander leaves in terms of their lightness (L^* value), greenness (negative a^* value), and yellowness (positive b^* value). The state of FD had the highest L^* value (34.92 ± 3.86), while the state of MD had the lowest L^* value (16.17 ± 2.42). FD resulted in increased greenness and increased yellowness, attributed to controlled temperature, uniform drying, reduced oxidation, and protection from light (Nurhaslina *et al.*, 2022). Conversely, MD exhibited decreased greenness and decreased yellowness, likely due to induced high temperatures, rapid oxidation, rapid moisture loss, and potential Maillard reactions during the drying process (Alkanan *et al.*, 2024; Uribe *et al.*, 2016). Additionally, the replacement of magnesium in chlorophyll by hydrogen, converting chlorophyll to pheophytin, may contribute to this observation (Madhava Naidu *et al.*, 2016). The L^* values for SD and CD were 31.85 ± 0.21 and 34.55 ± 0.08 , respectively, showing no significant difference ($p \leq 0.05$) in lightness among SD, CD, and FD. All drying methods except MD yielded a negative a^* value, indicating some retention of green color. The b^* values were higher in SD, CD, and FD compared to MD, likely because sun, cabinet, and freeze drying are gentler and more gradual, preserving more natural yellow pigments (carotenoids).

The chroma value was highest in CD (20.17 ± 0.23) and lowest in MD (11.12 ± 0.82), with the total color change being lowest in CD (2.32 ± 0.26) and highest in MD (23.53 ± 2.19). The high chroma in the CD indicates a bright, intense green color, suggesting freshness, visual appeal, and potentially better nutritional quality (Bishnoi *et al.*, 2020). The lower total color change in coriander leaves dried using cabinet drying is attributed to the controlled, gentle, and uniform drying conditions that preserve natural pigments and minimize degradation processes responsible for color changes (Shafi *et al.*, 2020).

Table 4.1: The color value of coriander leaves treated with different drying methods

Sample	L*	a*	b*	Chroma	Total Color Change (ΔE)
SD	31.85±0.21 ^a	-2.21±0.02 ^{bc}	18.69±0.10 ^b	18.82±0.10 ^{ab}	4.48±0.21 ^{bc}
CD	34.55±0.08 ^a	-3.29±2.24 ^c	19.82±0.29 ^b	20.17±0.23 ^a	2.32±0.26 ^c
MD	16.17±2.42 ^b	4.18±2.08 ^a	10.18±0.64 ^c	11.12±0.82 ^c	23.53±2.19 ^a
FD	34.92±3.86 ^a	-0.27±0.15 ^b	17.79±1.91 ^b	17.80±1.90 ^b	5.81±1.26 ^b

Here, SD=Sun dried sample, CD= Cabinet dried sample, MD= Microwave dried sample, FD= Freeze dried sample; If there is a significant difference between the means in a column, it will be shown by distinct superscripts ($p \leq 0.05$)

Table 4.2 presents the weight loss, moisture content, and drying time of dried coriander leaves. Every sample was dried until a consistent weight was reached, and each treatment's drying duration was noted. Notably, MD at 1.28 hours considerably shortened the drying period of coriander leaves as compared to SD at 5 hours, CD at 3.15 hours, and FD at 17 hours. Comparing microwave processing to traditional oven drying, a significant drying time decrease was shown (Hihat *et al.*, 2017). Similarly, Therdthai & Zhou, (2009) found that peppermint dried significantly faster in a microwave vacuum dryer than it would in a hot air dryer. Although microwave energy reduces drying time, it negatively impacts the color quality of coriander leaves. Among the four drying methods, CD achieved the best results in terms of drying time, color, and nutritional quality, offering energy savings and cost reduction (Bishnoi *et al.*, 2020).

The maximum weight loss (88.27%) was observed in coriander leaves dried using MD, followed by those dried with FD and CD. The least weight loss (84.31%) was exhibited by the sample dried using SD. These findings are consistent with Hayat, (2020), who reported highest weight loss (87.1%) in peppermint leaf samples dried in a hot-air conventional oven for 180 minutes at 80°C, and samples dried in a microwave oven for 8 minutes at 900W (86.85%).

The highest moisture content in coriander leaves was found in SD (5.07%), and the lowest was found in MD (4.10%). This result aligns with Hayat, (2020), who reported a moisture

content of 4.03% in peppermint dried using microwave drying at 450W. With a maximum moisture level of 7.39% in shadow-dried samples, the moisture content of the dried samples in this investigation was within the range for dried drumstick leaves reported by Joshi & Mehta (2010).

Table 4.2: Drying time, weight loss, and moisture content of coriander leaves treated with different drying methods

Sample	Drying Time (Hour)	Weight Loss (%)	Moisture Content (%)
SD	5	84.31±0.01 ^d	5.07±0.42 ^a
CD	3.15	85.09±0.02 ^c	4.89±0.64 ^a
MD	1.28	88.27±0.02 ^a	4.10±0.10 ^b
FD	17	87.29±0.01 ^b	4.40±0.09 ^{ab}

Here, SD=Sun dried sample, CD= Cabinet dried sample, MD= Microwave dried sample, FD= Freeze dried sample; When two columns' means differ noticeably from one another, it is indicated by separate superscripts ($p \leq 0.05$)

4.2 Total phenolic content and total flavonoid content of coriander leaves

It is well known that phenols are strong antioxidants that are good for human health, especially when it comes to preventing degenerative diseases (Islam *et al.*, 2023). Table 4.3 displays the total phenolic content of dried coriander leaves. The SD sample had the greatest TPC, measuring 120.26±3.02 µg GAE/gDM. This was considerably ($p \leq 0.05$) higher than the TPCs of the CD, MD, and FD samples, with the order of TPC being SD > CD > MD > FD. The higher TPC in the SD sample may be attributed to the moderate temperature used in sun drying. According to (Hihat *et al.*, 2017), very high drying temperatures can reduce TPC in samples. Uribe *et al.* (2015) also noted that some bioactive phenols are heat labile, which could explain why the TPC in the CD sample was significantly lower than in the SD sample. Hayat *et al.* (2010) further suggested that higher temperatures may lead to the thermal degradation of polyphenolic compounds.

Perhaps as a result of the tremendous heat produced by microwaves raising the temperature and vapor pressure inside the plant tissue, the MD sample had the third-highest TPC. Plant cell wall polymers were disrupted as a result, making it easier to extract more phenolics. (Hussain *et al.*, 2024).

Kozłowska *et al.* (2021) found that the TPC of freeze-dried coriander was 50.57 ± 1.59 g GAE/kg extract, which, although lower, was approximately similar to the findings of this study. Freezing and other technical operations may lead to changes in TPC. The creation of phenolic complexes with other leaf elements such as proteins, carbohydrates, and anti-nutritional substances, which restrict their extractability, could be another explanation for the drop in phenolic content (Shafi *et al.*, 2020). It is recognized that certain phenolic compounds combine with elements of plant cell walls to generate an insoluble form (Shafi *et al.*, 2020). In plants, phenols primarily take the form of aglycones, glycosides, and esters, or are attached to the cell wall (Hamrouni-Sellami *et al.*, 2013). These factors could explain the lower TPC in freeze-dried coriander leaves.

Flavonoids are a prominent category of plant-based compounds that can effectively combat a range of degenerative illnesses, such as cancer, cardiovascular diseases, diabetes, inflammation, and hypersensitivity (Islam *et al.*, 2023). Table 4.3 represents the total flavonoid content (TFC) of coriander leaves dried using different methods. The sun-dried (SD) sample had the highest TFC, measured at 64.33 ± 2.97 μg QE/g DM, while the freeze-dried (FD) sample had the lowest TFC, measured at 30.67 ± 0.82 μg QE/g DM, following the trend: SD > CD > MD > FD.

The uniformly moderate temperature of sun drying and the high output power of microwave drying resulted in the maximum yield of TFC from the samples (Dong *et al.*, 2011; Hihat *et al.*, 2017). Thus, the highest TFC was found in the sun-dried samples. The flavonoid content was reduced when the samples were exposed to microwave irradiation for longer periods, resulting in lower TFC in MD samples compared to SD and CD samples (Hayat *et al.*, 2010).

In contrast, the TFC from cabinet drying was significantly lower than from sun drying. This decrease could be the result of macromolecules being lost during heat treatment in extreme drying conditions, namely the temperature and length of time used (Hihat *et al.*, 2017). Uribe *et al.* (2016) also noted that some bioactive phenols are heat labile, which could explain why the TFC in the CD sample was significantly lower than in the SD sample.

Because plant cell wall polymers were not sufficiently disrupted by the freezing temperature during the freeze-drying process, the TFC was the lowest and the yield of TFC was lower. It is known that certain macromolecules, such as flavonoids, combine with elements of plant cell walls to generate an insoluble form (Hihat *et al.*, 2017; Shafi *et al.*, 2020).

Table 4.3: Total Phenolic Content and Total Flavonoid Content of coriander leaves with different drying methods

Sample	TPC ($\mu\text{g GAE/g DM}$)	TFC ($\mu\text{g QE/g DM}$)
SD	120.26 $\pm$ 3.02 ^a	64.33 $\pm$ 2.97 ^a
CD	102.44 $\pm$ 0.30 ^b	56.42 $\pm$ 1.68 ^b
MD	79.99 $\pm$ 1.51 ^c	51.11 $\pm$ 0.54 ^c
FD	65.42 $\pm$ 0.38 ^d	30.67 $\pm$ 0.82 ^d

Here, SD=Sun dried sample, CD= Cabinet dried sample, MD= Microwave dried sample, FD= Freeze dried sample; The different superscripts in a column indicate that the means are significantly different from each other ($p \leq 0.05$)

4.3 Antioxidant activity and antidiabetic properties of coriander leaves

Figure 4.1 shows the antioxidant activity of coriander leaves dried using various methods, including sun drying, cabinet drying, microwave drying, and freeze drying. The antioxidant values for these drying methods were 2.30 $\pm$ 0.063, 2.22 $\pm$ 0.01, 2.04 $\pm$ 0.006, and 2.14 $\pm$ 0.008 $\mu\text{MTE/gm DM}$, respectively. The significantly highest antioxidant value was observed in the SD samples, while the significantly lowest was in the MD samples. Sun drying enhances phytochemical content and reduces water activity, which inactivates enzymes and retains high antioxidant capacity in the dried samples (Jayasuriya *et al.*, 2023). This could explain the superior antioxidant activity in sun-dried coriander leaves. Higher temperatures during cabinet drying can produce and accumulate melanoidins generated from Maillard processes, which are substances with variable levels of antioxidant activity that can improve antioxidant capacity overall (Hihat *et al.*, 2017). Freeze drying affects the content of biologically active compounds, influencing the antioxidant potential of coriander leaves (Kozłowska *et al.*, 2021). However, prolonged drying at low temperatures, characteristic of freeze drying, can decrease antioxidant capacity (Vega-Gálvez *et al.*, 2009), resulting in lower antioxidant activity in freeze-dried samples. When microwave drying occurs at temperatures higher than 60°C, antioxidant chemicals may deteriorate and lose some of their action (Hihat *et al.*, 2017). High temperatures may induce oxidative condensation or the decomposition of thermolabile compounds (Hamrouni-Sellami *et al.*, 2013), which likely accounts for the lowest antioxidant activity observed in microwave-dried coriander leaves. The total antioxidant capacity is influenced by the presence of additional antioxidants, potential antagonistic or synergistic interactions amongst phenolic antioxidants, and the amount and activity of phenolic compounds (Kozłowska *et al.*, 2021). As a result, a number of variables,

such as the kind of extraction solvent, the drying technique, the antioxidant assays employed, and the interactions between different antioxidant processes, might affect antioxidant activity (Vega-Gálvez *et al.*, 2009).

Diabetes mellitus (DM) is a metabolic disease marked by elevated blood sugar levels brought on by irregularities in the metabolism of fat, protein, and carbohydrates. The prevalence of diabetes is rapidly increasing each year in Bangladesh, and long-term use of antidiabetic drugs can lead to various side effects. Coriander, particularly its seeds and leaves, has been used as an herbal remedy for diabetes mellitus (Prachayasittikul *et al.*, 2018). Figure 1(B) illustrates the anti-diabetic properties of dried coriander leaves, with the highest α -glucosidase inhibitory activity observed in CD, followed by SD, FD, and MD. This finding is consistent with Maser *et al.* (2023), who reported the greatest α -glucosidase inhibitory activity in coriander leaves dried using oven drying, followed by dehydration drying and freeze-drying. Similarly, Khoo *et al.* (2015) discovered that, in comparison to freeze drying, oven drying produced a greater inhibitory activity in the *Clinacanthus nutans* leaves and stems. It has been proposed that the drying process increases the plant cell walls' brittleness, which increases their susceptibility to breaking down and allows for the extraction of more bioactive chemicals (Khoo *et al.*, 2015). The plant cell walls' intercellular gaps may rupture during heat treatments like cabinet drying, releasing more phytochemicals from the plant matrix (Khoo *et al.*, 2015).

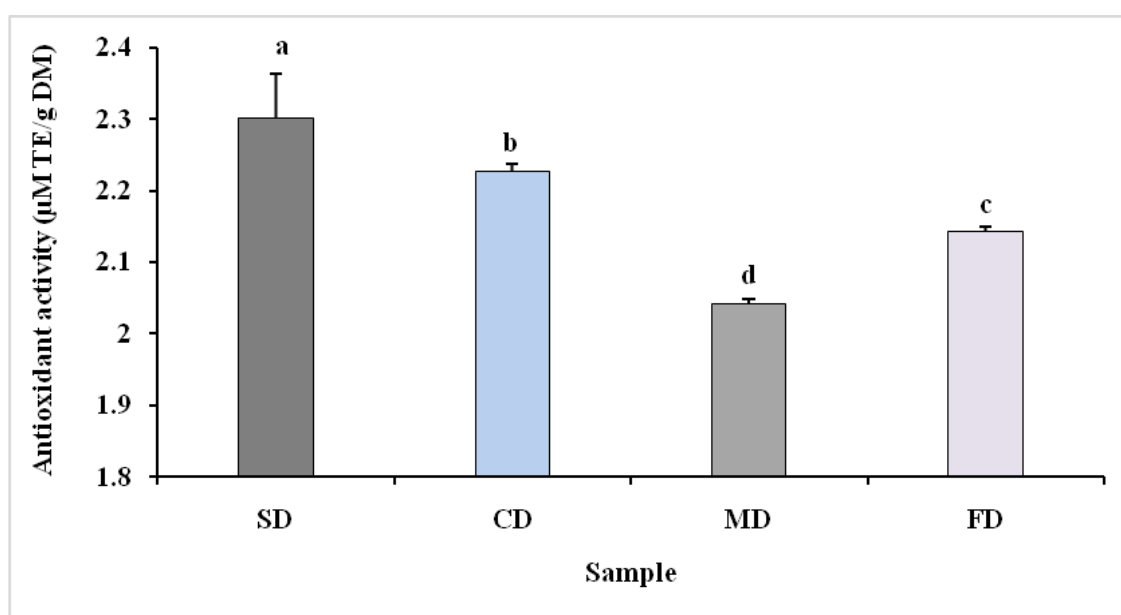


Figure 4.1: Antioxidant activity of dried coriander leaves where SD=Sun dried sample, CD=Cabinet dried sample, MD=Microwave dried sample, and FD=Freeze dried sample. The different superscripts in the figure indicate that the means differ significantly from each other ($p \leq 0.05$)

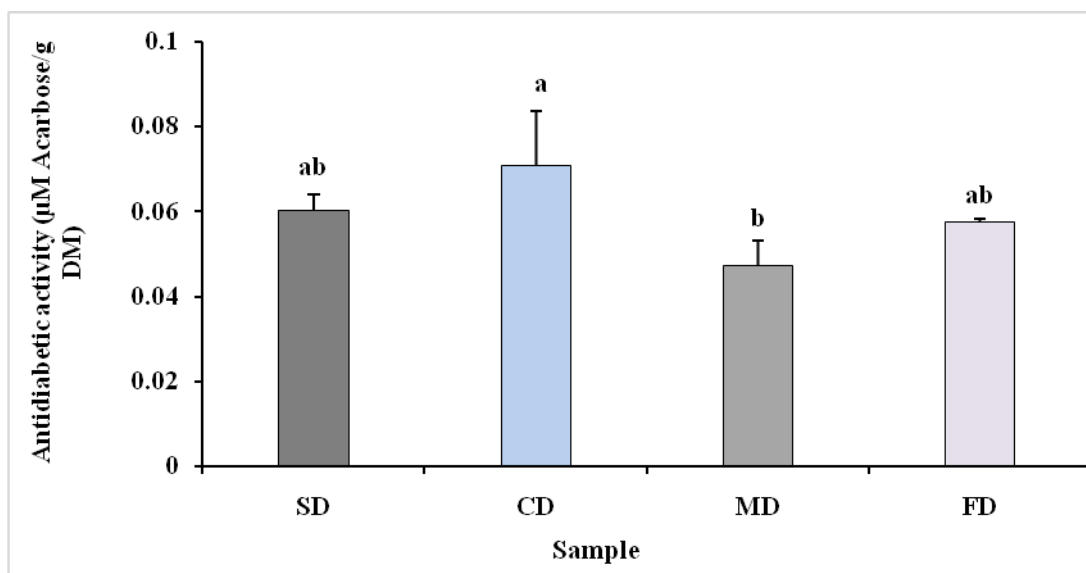


Figure 4.2: Antidiabetic activity of dried coriander leaves where SD=Sun dried sample, CD=Cabinet dried sample, MD=Microwave dried sample, and FD=Freeze dried sample. The different superscripts in the figure indicate that the means differ significantly from each other ($p \leq 0.05$)

4.4 Total chlorophyll, chlorophyll a and b in dried coriander leaves

Chlorophyll retention is a key quality measure in green vegetables. Coriander leaves have a total chlorophyll content ranging from 8.71 µg/ml to 34.8 µg/ml (Figure 4.3). At 34.68 µg/ml, CD had the greatest total chlorophyll concentration, followed by FD at 31.78 µg/ml. At 8.71 µg/ml, the total chlorophyll concentration obtained by the MD technique was the lowest. Modest drying times and regulated temperatures may be the reason for the highest overall chlorophyll content in CD of all drying techniques Bishnoi *et al.*, (2020). Longer drying times can accelerate the conversion of chlorophyll to brown pigment pheophytins Ahmed *et al.*, (2001).

The results of this investigation are consistent with data published by Komes *et al.* (2011), which shows that, in contrast to freeze-drying and air-drying, microwave drying significantly degrades all bioactive components in plants. Additionally, Sahar M Kamel, (2013) observed that microwave-dried coriander leaves had 78.3% less chlorophyll than air-dried samples. The various drying techniques had a substantial ($p \leq 0.05$) impact on the concentrations of both chlorophyll a and chlorophyll b (Figure 4.3). FD and CD had the highest concentrations of chlorophyll a and b, measuring 13.55 µg/ml and 22.15 µg/ml, respectively. MD had the lowest results, 3.19 µg/ml, and 5.51 µg/ml, respectively. The rapid and uneven heating characteristics of microwave drying can lead to a more significant degradation of chlorophyll

in coriander leaves compared to the more controlled and gentler processes of sun, cabinet, and freeze-drying (Valentina & Savvas, 2022).

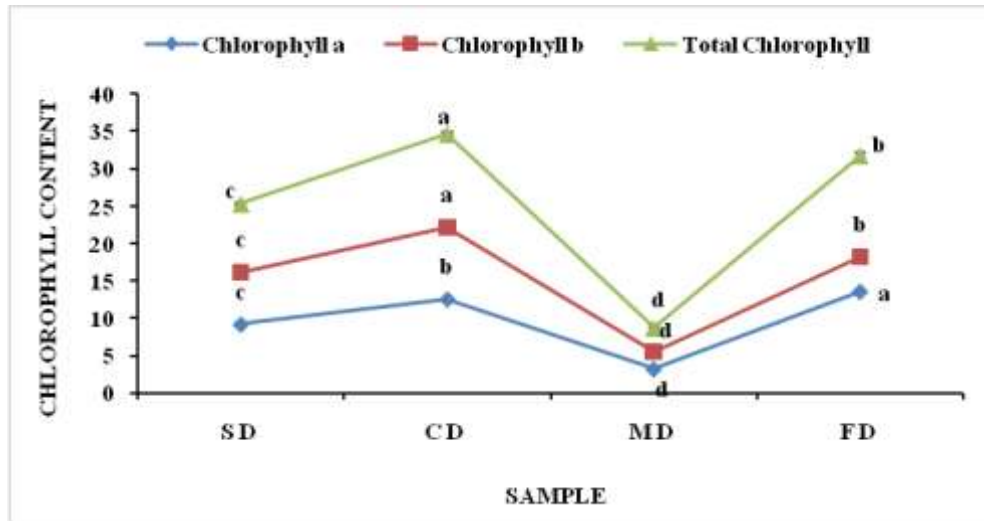


Figure 4.3: Total chlorophyll, chlorophyll-a, and chlorophyll-b of dried coriander leaves where SD=Sun dried sample, CD=Cabinet dried sample, MD=Microwave dried sample, and FD=Freeze dried sample. Different letters on each line indicate significant differences among the samples at $p \leq 0.05$.

4.5 Sensory evaluation of dried coriander leaves

Figure 4.4 illustrates the results of the sensory evaluation of dried coriander leaves using various drying techniques. These techniques significantly impacted sensory quality. The hedonic scores for visual inspection were higher for SD and FD than for CD and MD. This is likely because sun drying and freeze-drying are less aggressive methods that better preserve the natural color and structure of coriander leaves, resulting in superior visual quality compared to cabinet and microwave drying. Additionally, freeze-drying received the highest scores for texture and touch. However, the aroma, taste, and overall quality were highest on CD. This might be because cabinet drying provides a controlled environment that balances temperature and airflow, effectively preserving the aromatic and flavor compounds in coriander leaves Bishnoi *et al.*, (2020). This leads to superior aroma, taste, and overall quality compared to the more extreme or less controlled conditions of freeze drying, sun drying, and microwave drying. MD received the lowest sensory scores in all attributes among all drying methods. This might be due to microwave drying's rapid and uneven heating process, which can significantly damage the delicate structure and compounds in coriander leaves Valentina & Savvas, (2022).

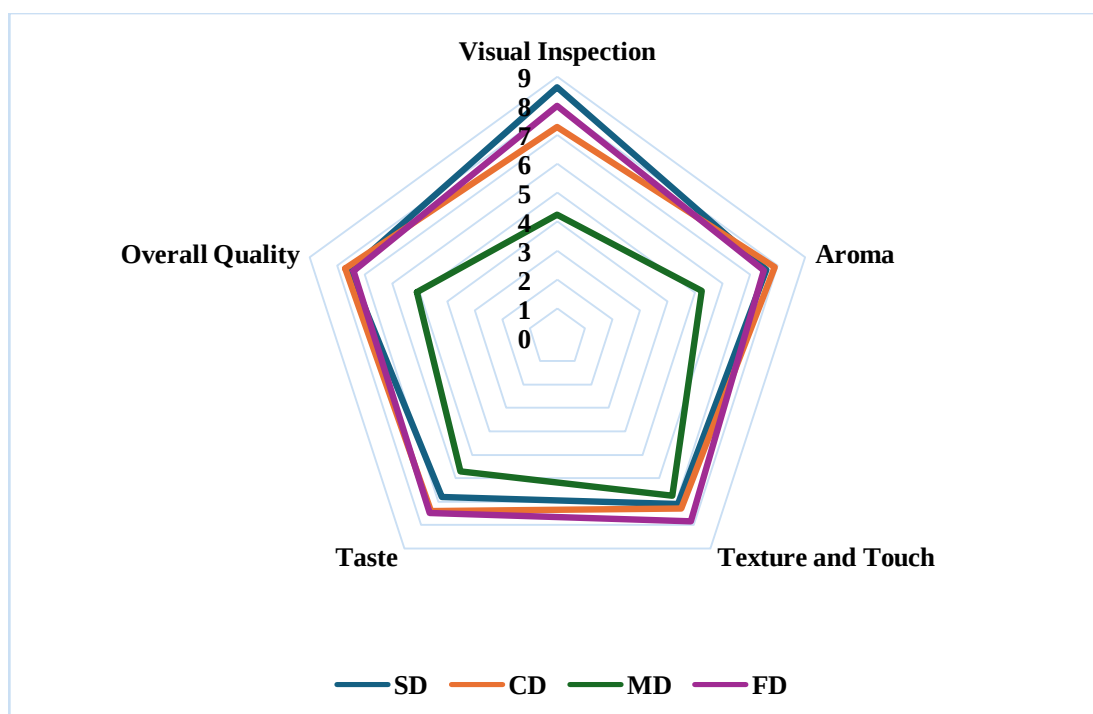


Figure 4.4: Mean sensory score of dried coriander leaves (A) where SD=Sun dried sample, CD=Cabinet dried sample, MD=Microwave dried sample, and FD=Freeze dried sample. Mean sensory evaluation of soup prepared with dried coriander leaves (B). Here, sample 1=soup with sun-dried coriander leaves, sample 2= soup with cabinet-dried coriander leaves, sample 3= soup with microwave-dried coriander leaves, sample 4= soup with freeze-dried coriander leaves, and control= soup with fresh coriander leaves

4.6 Sensory evaluation of soup prepared with dried coriander leaves

Figure 4.5 shows that vegetable soup mixed with dried coriander leaves outperformed soup mixed with fresh coriander leaves. The figure demonstrates that Sample 1 received the highest sensory scores for color compared to Samples 2, 3, 4, and the control. Additionally, Sample 2 achieved the highest scores for texture, flavor, taste, and overall acceptability than all of the other samples. Samples 3 and 4 received the lowest sensory scores among all samples.

This may be due to microwave-dried coriander leaves suffering from a significant loss of flavor and aroma due to rapid and uneven heating. Freeze-dried leaves, while structurally intact, may not retain as strong a flavor profile and might have rehydration issues. In contrast, cabinet-dried and sun-dried leaves retain more of the essential oils and flavor compounds, resulting in better sensory scores when mixed with vegetable soup.

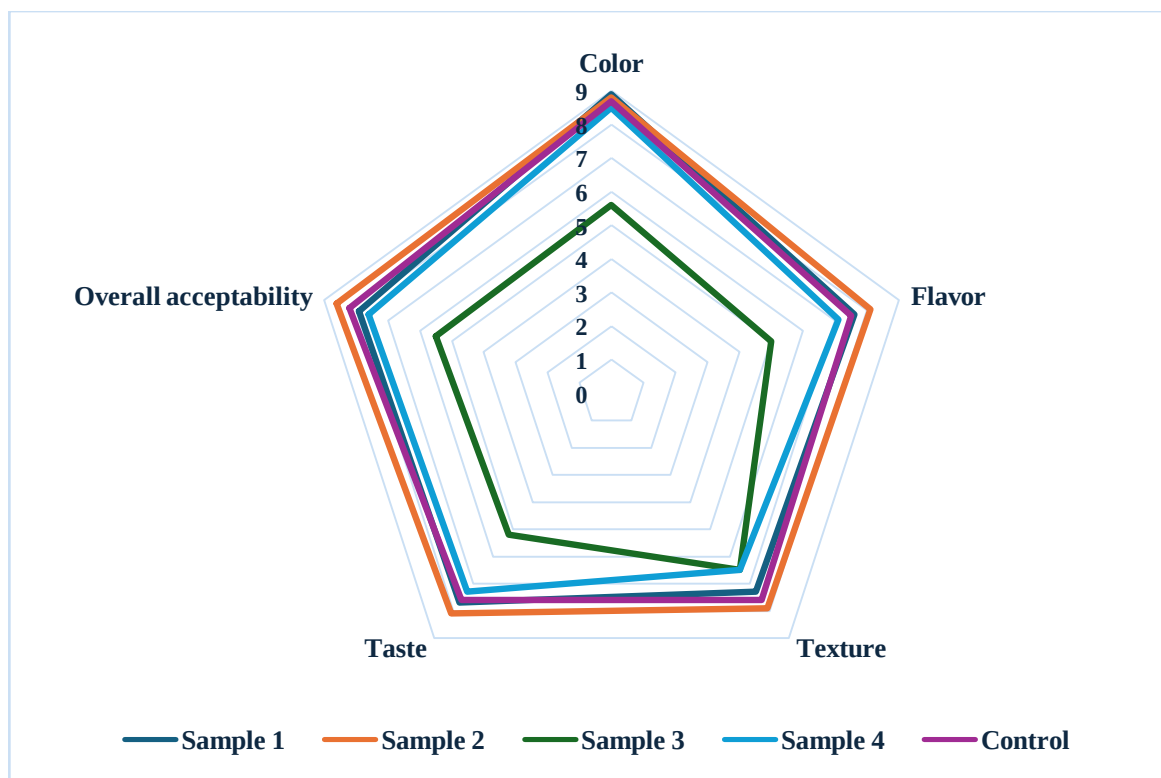


Figure 4.5: Mean sensory evaluation of soup prepared with dried coriander leaves. Here, sample 1=soup with sun-dried coriander leaves, sample 2= soup with cabinet-dried coriander leaves, sample 3= soup with microwave-dried coriander leaves, sample 4= soup with freeze-dried coriander leaves, and control= soup with fresh coriander leaves

CHAPTER- V

CONCLUSION

This study looked at the physicochemical, chlorophyll content, and bioactive characteristics of coriander leaves after drying them using different techniques. The following four methods of drying were employed: freeze drying (FD), microwave drying (MD), cabinet drying (CD), and sun drying (SD). The results indicated no significant differences ($p \leq 0.05$) in the L^* value among SD, CD, and FD, except for MD. All drying methods, except MD, had a negative a^* value, indicating the highest retention of green color. CD exhibited high chroma and low total color change, whereas MD showed low chroma and high total color change. Despite MD having the shortest drying time, it resulted in the highest weight loss. The maximum TPC, TFC, and antioxidant activity values were reached by SD. Compared to MD and FD, CD exhibited greater TPC, TFC, and antioxidant activity. Conversely, CD showed a higher concentration of total chlorophyll than MD. In addition, CD had better antidiabetic qualities than the other drying techniques. Additionally, the CD scored highest on sensory evaluations when applied to vegetable soup and dry leaves.

These results suggest that cabinet drying offers a more cost-effective, efficient, and regulated method of drying coriander leaves than the sun, microwave, or freeze drying, while also better-balancing quality, cost, and efficiency.

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